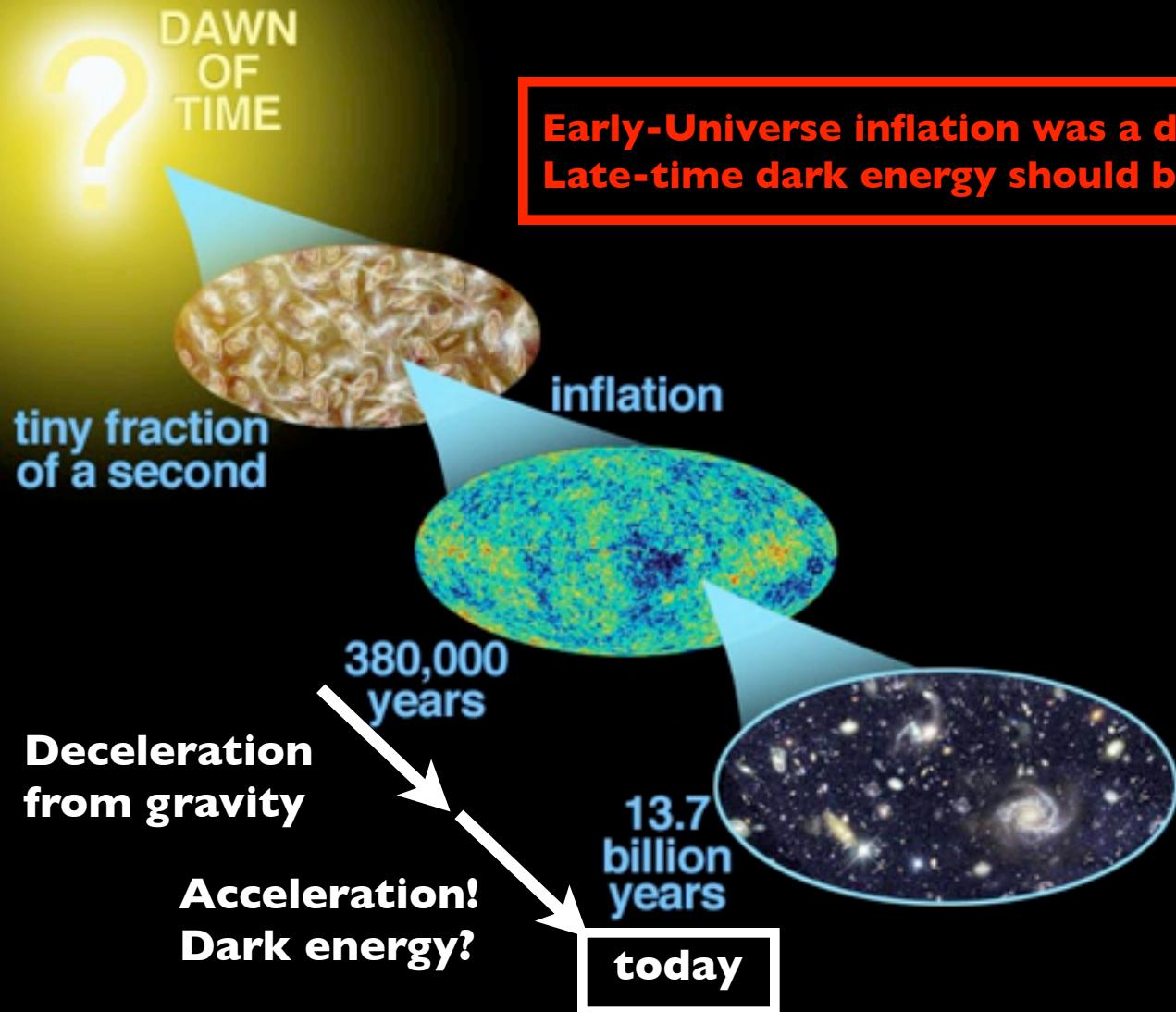


BigBOSS: **Ground-Based Stage IV** **BAO Experiment**

-
- I. BigBOSS science**
 - II. Instrument**
 - III. Imaging + Targets**
 - IV. Pilot surveys**
 - V. Questions**

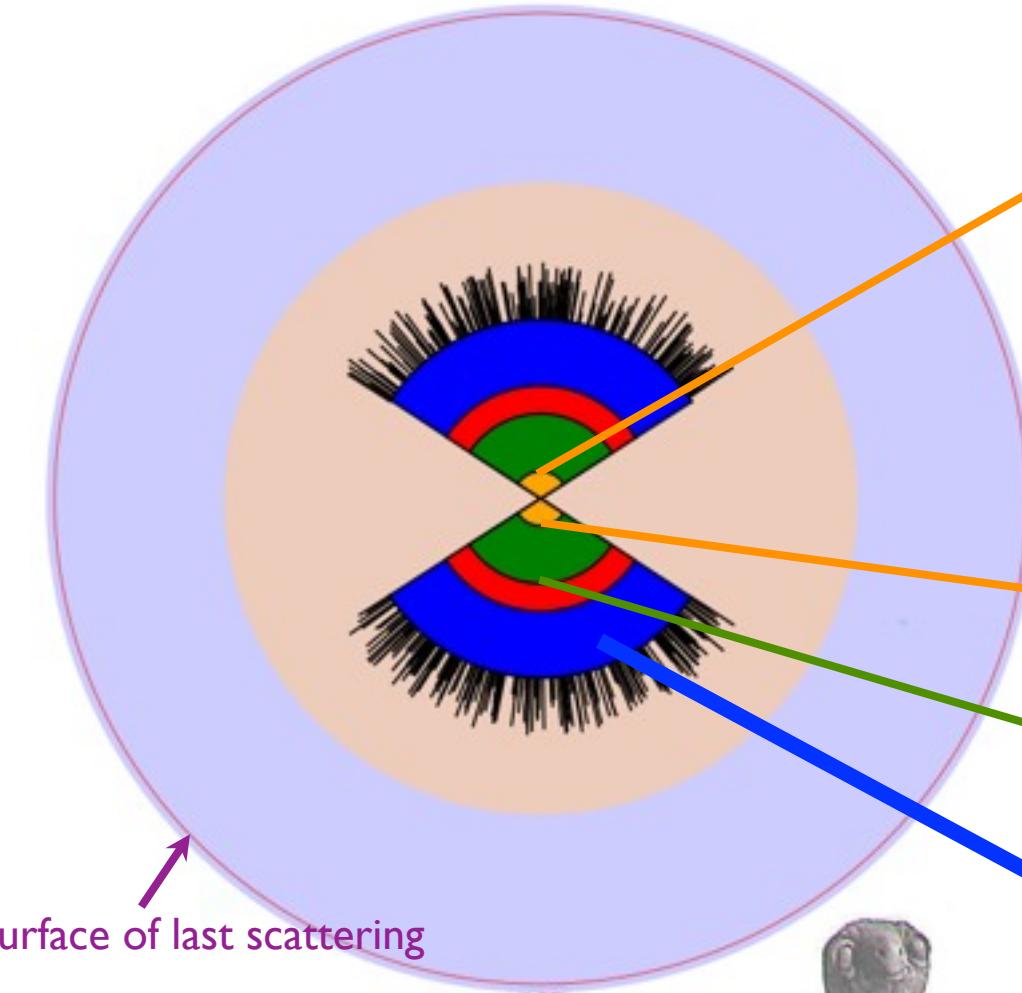
-
- I. BigBOSS science**
 - II. Instrument**
 - III. Imaging + Targets**
 - IV. Pilot surveys**
 - V. Questions**



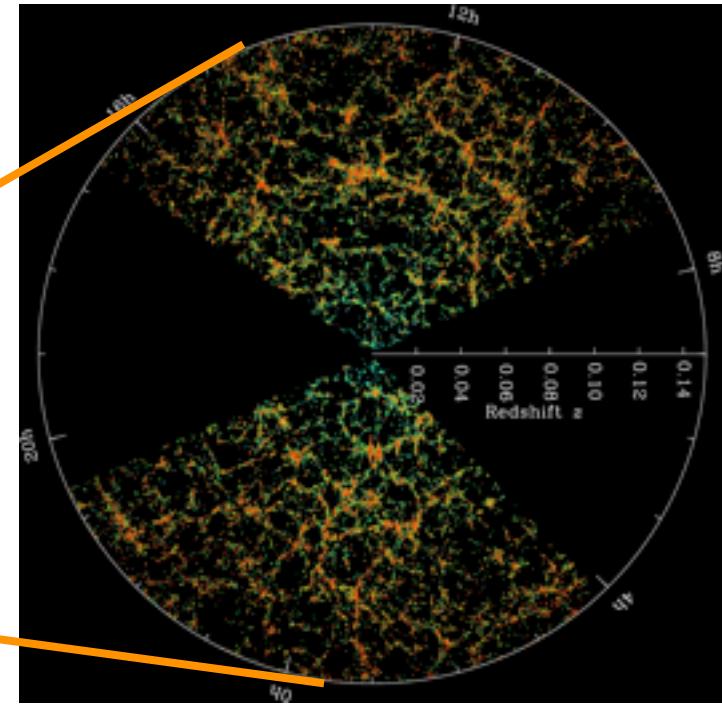
Science Goals: 50 million redshifts

Sensitivity to new physics scales as volume surveys -- # of modes

Our observable Universe



Volume mapped by SDSS + SDSS-II



Volume to be mapped by SDSS-III/BOSS
(ca. 2015)

BigBOSS @NOAO



The turtle is at Purple Mountain Observatory

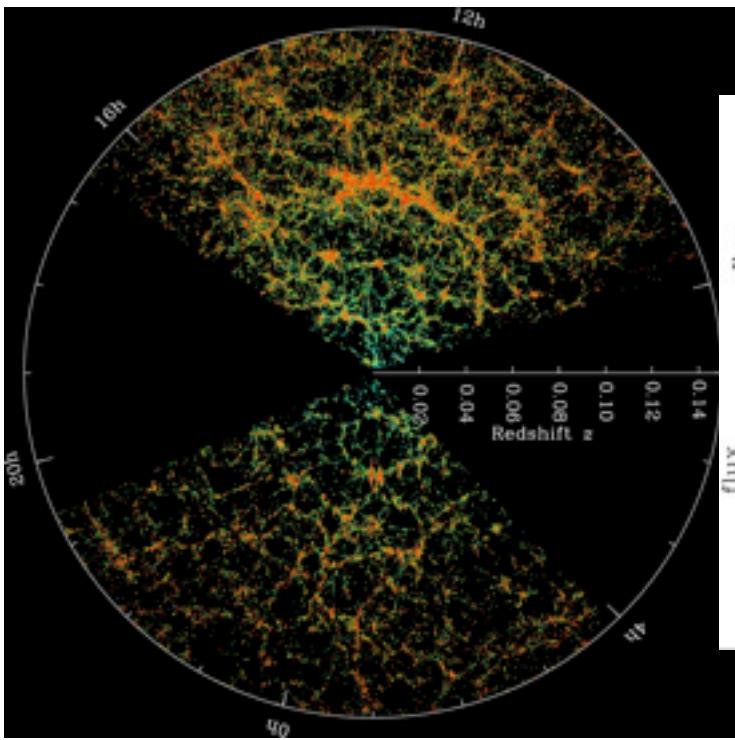


Science Goals: 50 million redshifts

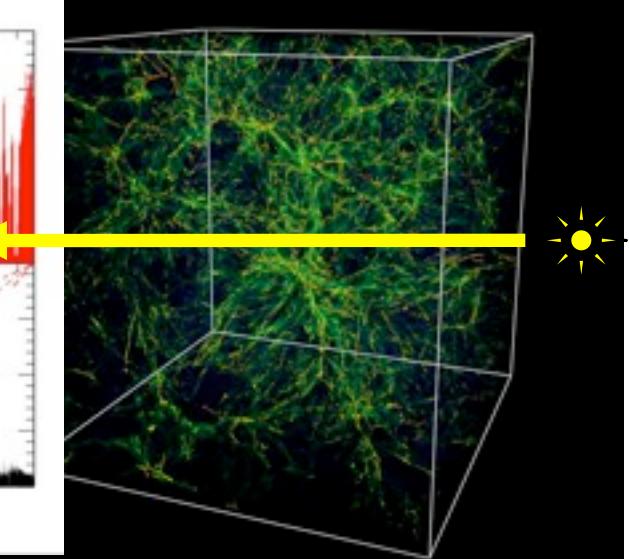
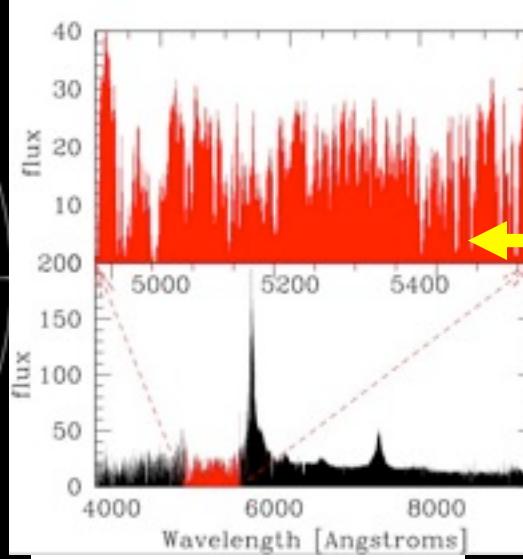
Simultaneous spectroscopic surveys from 2015-2025

- BAO from 50 million galaxies at $0.2 < z < 2.0$
- BAO from 1 million QSOs at $2 < z < 3$

Galaxy map



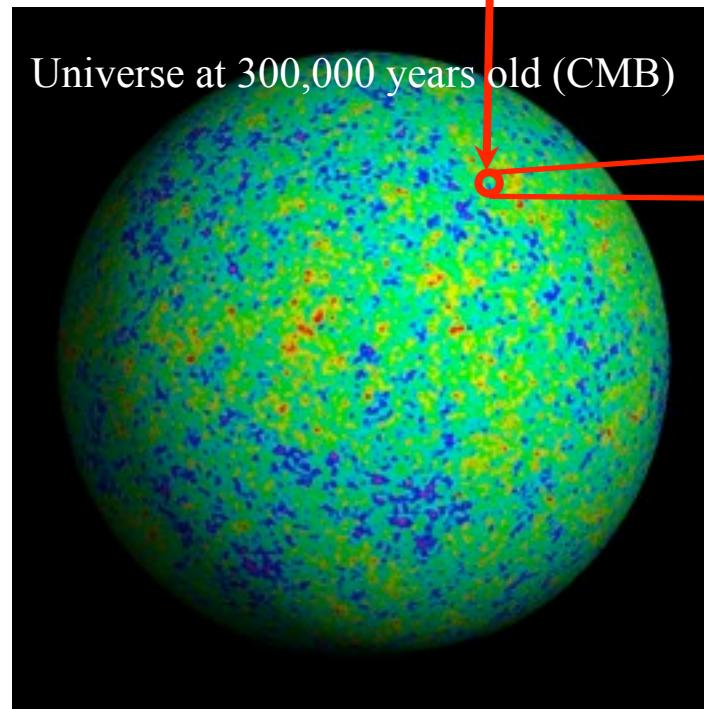
QSOs as back-light to hydrogen gas



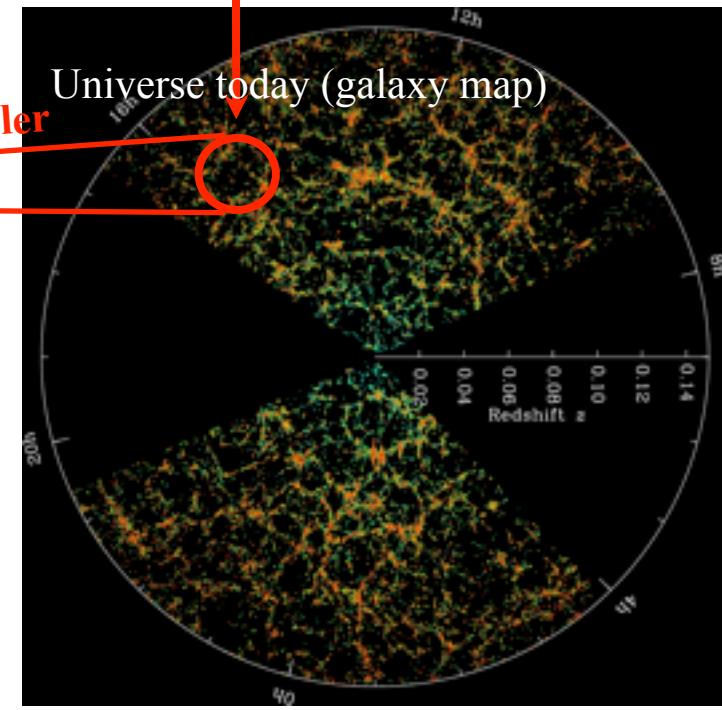
Science Goals: BAO and dark energy

Precision dark energy probe from BAO scale
Inflation probe from non-gaussian fluctuations

These fluctuations of 1 part in 10^5
gravitationally grow into...

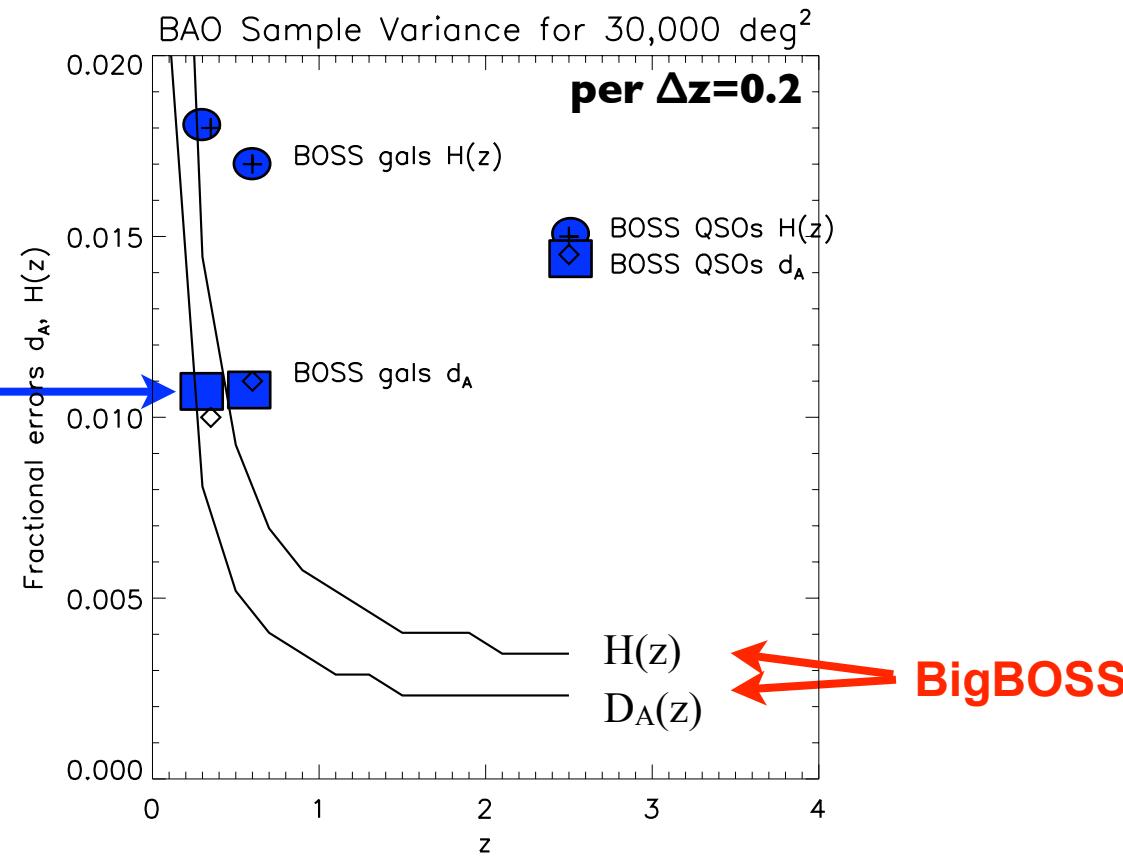


...these ~unity fluctuations today



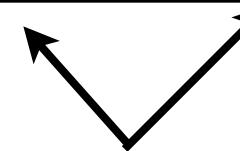
Science Goals: BAO and dark energy

SDSS-III/BOSS



Science Goals: BAO and dark energy

	BOSS (Stage III)	BigBOSS-North (Stage IV)	JDEM-BAO (Stage IV)	BigBOSS-N+S (Stage IV)
Redshift range	$0 < z < 0.7$	$0 < z < 3.5$	$0.7 < z < 2.0$	$0 < z < 3.5$
Sky Coverage	10000 deg ²	14000 deg ²	20000 deg ²	24000 deg ²
Wavelength Range	360-1000 nm	340-1130 nm	1100–2000 nm	340nm–1130 nm
Spectral Resolution	1600-2600	2300-6100	200	2300-6100
DETF FoM	57	175	250	286
DETF FoM w/Stage III	107	240	313	338



BigBOSS equivalent to JDEM satellite for mapping BAO
BigBOSS full-sky on KPNO 4m + CTIO 4m

Broader science case for *fluctuation physics*

* Full $P(k)$

Neutrino mass

Curvature

* Redshift-space distortions

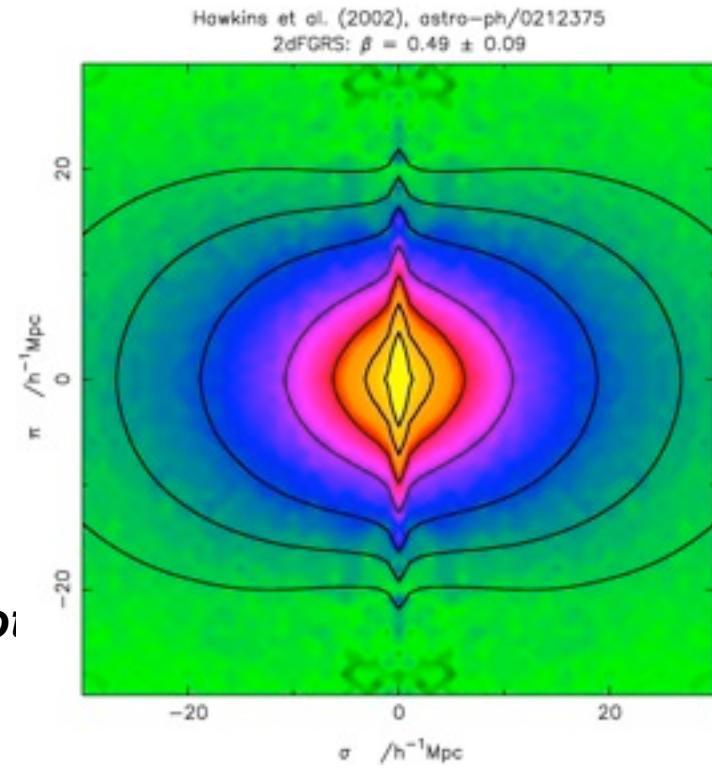
(grav. growth!)

* Multiple tracer methods

Non-gaussianity from multiple tracers

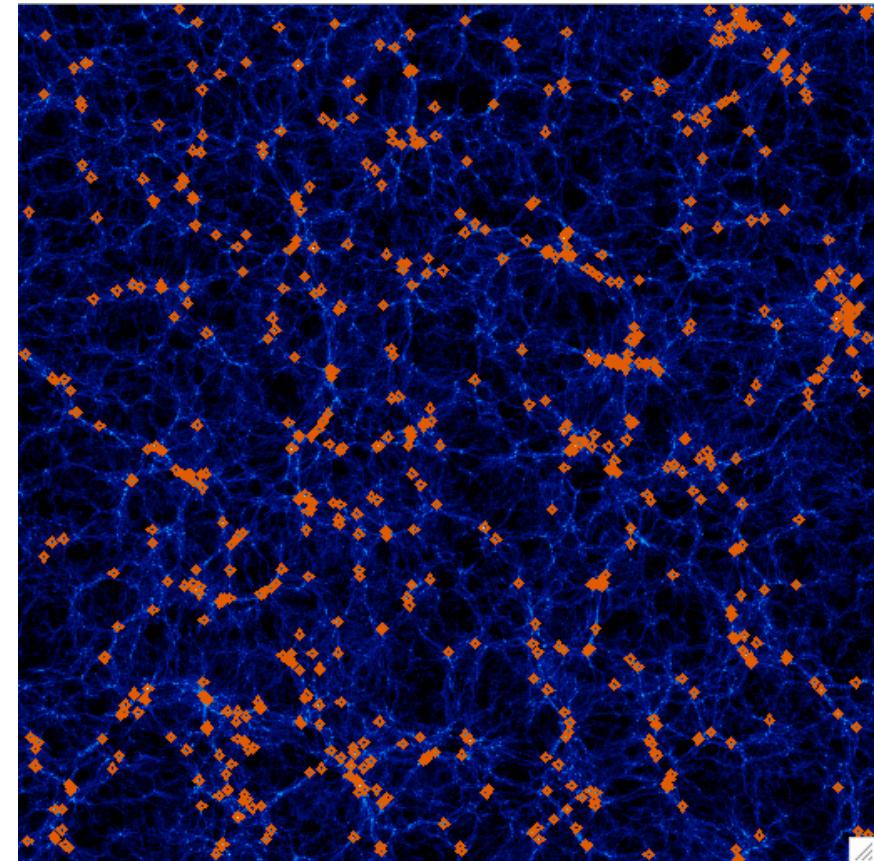
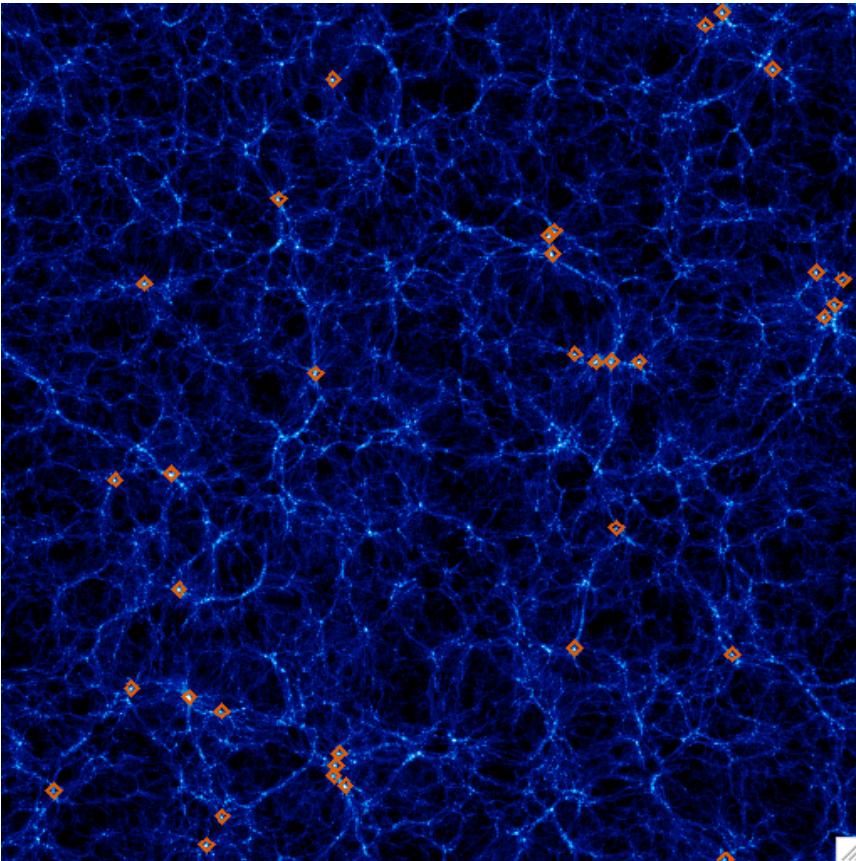
Avoid sample variance with x-power (not total power),

especially with WL mass maps



Questions: Desired n/volume?
Multiple tracer populations/bias?
Redshift precision (QSOs)?

Science Goals: N-body simulations...



Questions:

**“Ask not what [simulations] will do for you,
ask what you can do for your [simulations]” (J.F. Kennedy)**

-
- I. BigBOSS science**
 - II. Instrument**
 - III. Imaging + Targets**
 - IV. Pilot surveys**
 - V. Questions**

Instrument: Telescope

Kitt Peak 4-m (Mayall) at Kitt Peak, Arizona

SDSS-inspired:
simple, high-throughput

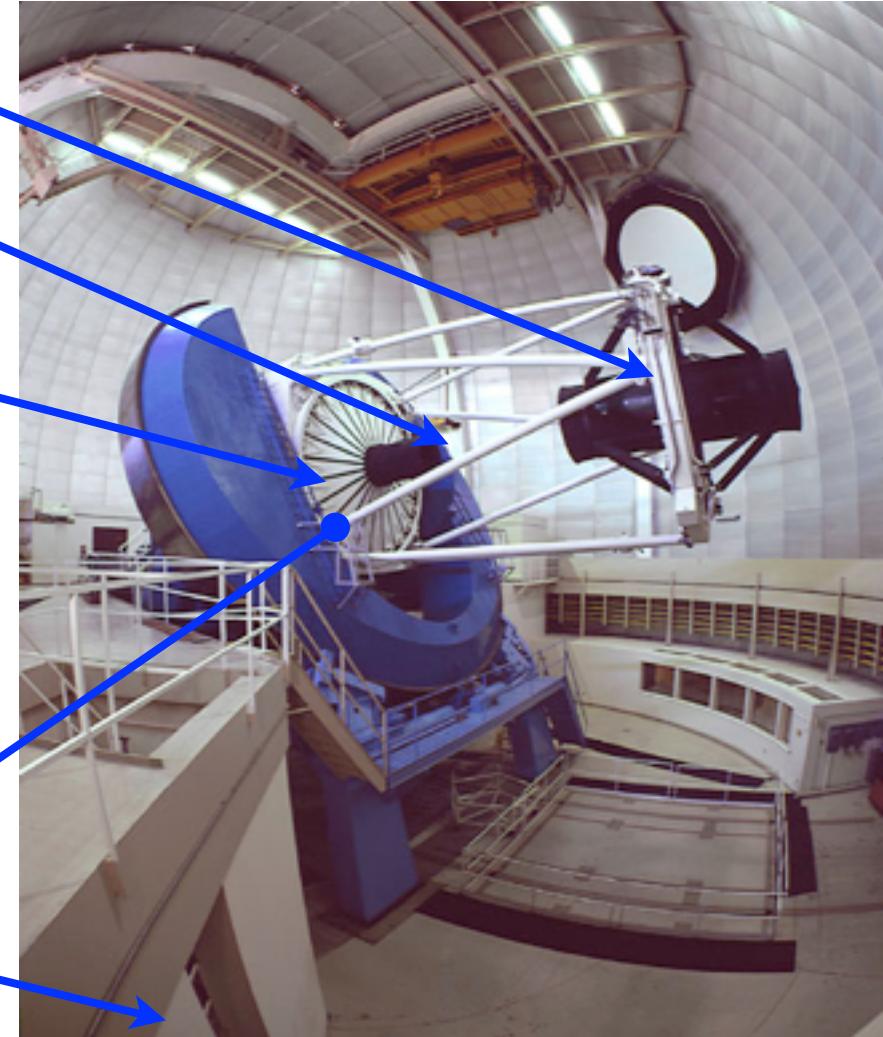
1.5-m f/5 secondary
enables 3° FOV

3-element corrector

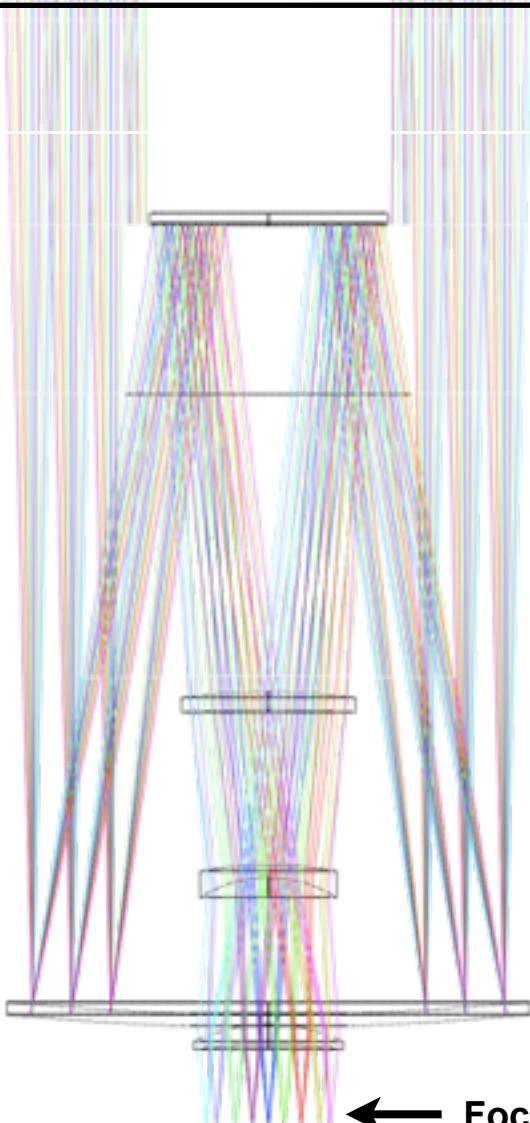
5000 fiber positioners
on 99-cm focal plane

Fiber run (bare fibers)

10 spectrographs



Instrument: Telescope optics



- Mayall is slow RC, making correction to **3° field** possible
- All magnification is in secondary
- Corrector lenses add no power
 - *Simple fused silica*
 - *No CaF*
- Manufacturing feasibility verified by the University of Arizona College of Optical Sciences
 - *Less challenging than previous optics, using profilometry + interferometry*
 - **Identical optics work at KPNO 4m + CTIO 4m**

Questions: Lens cell tolerances?
ADC necessary?
AR coatings at 1.2-m?

Instrument: Telescope optics



If we don't do this,
someone else will!

4-m class telescopes:

KPNO 4-m

CTIO 4-m

CFHT 3.6-m

Calar Alto 3.5-m

ARC 3.5-m (Apache Point)

WIYN 3.5-m (Kitt Peak)

Discovery Channel 4.2-m

WHT 4.2-m

ESO 3.6-m

SOAR 4.2-m

UKIRT 3.8-m

Galileo 3.58-m

ESO NNT 3.58-m

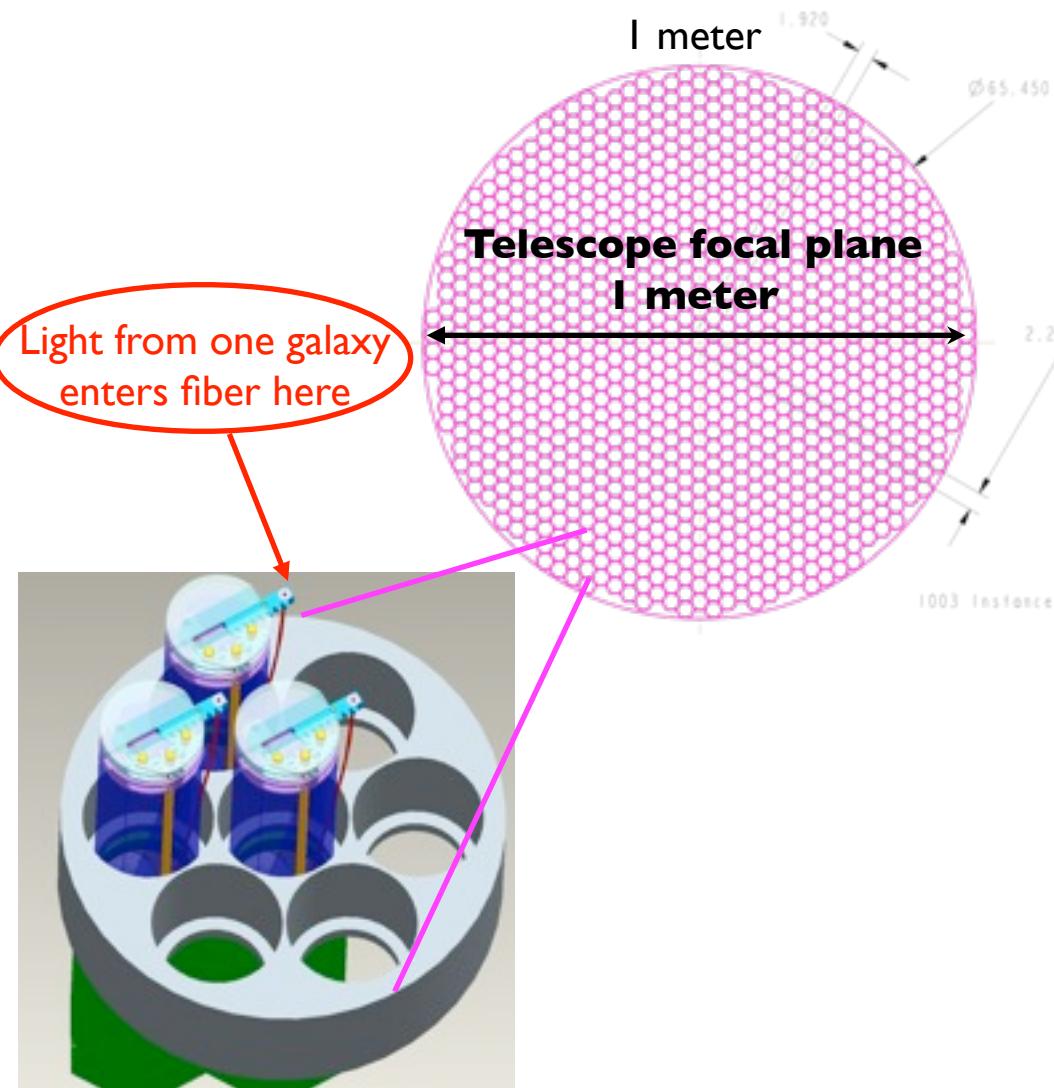
VISTA 4-m

AAT 3.9-m

3-deg possible

2-deg exists

Instrument: Fiber positioners x 5000

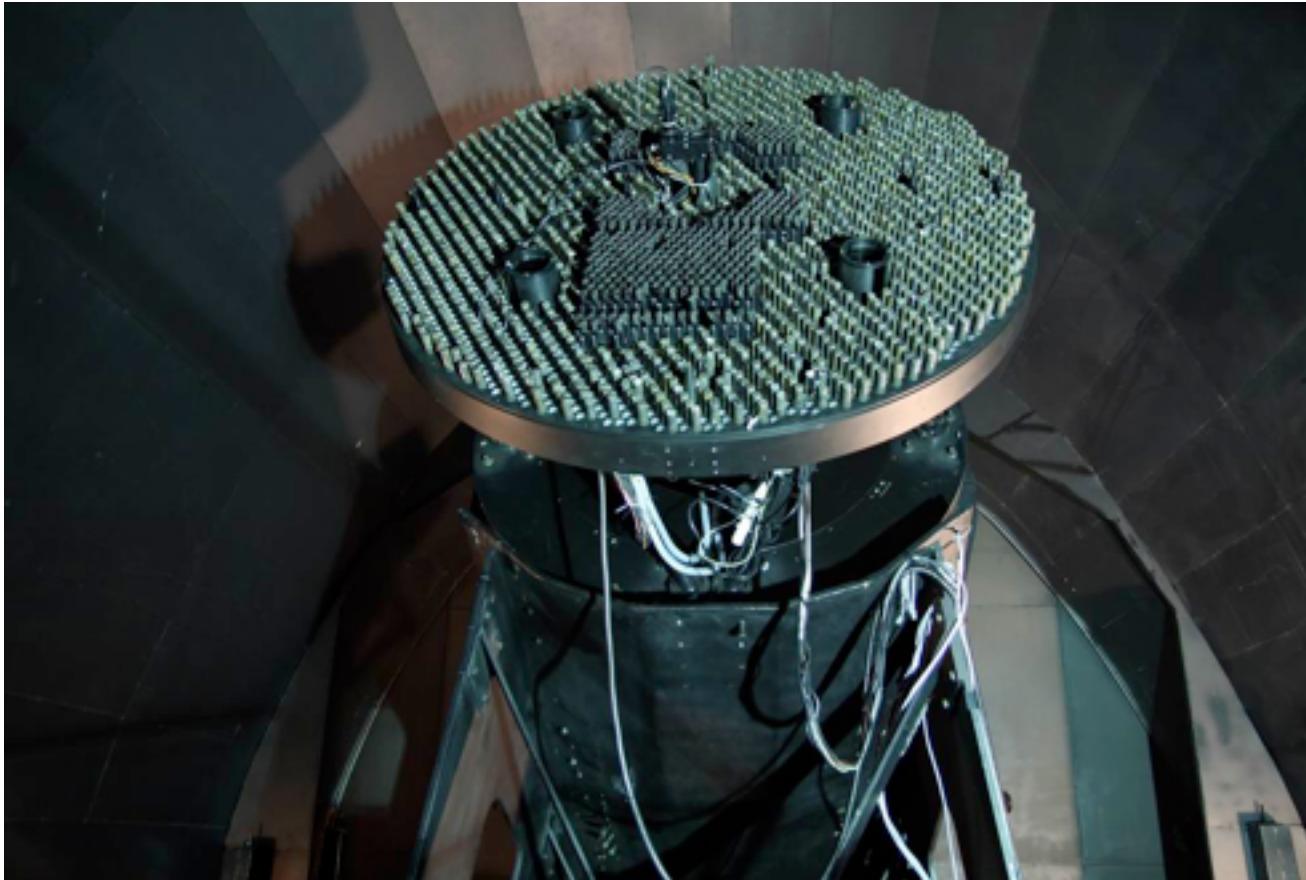


Instrument: Fiber positioners x 5000

LAMOST fiber positioner

Designed by Univ. of Science & Technology (USTC/China)

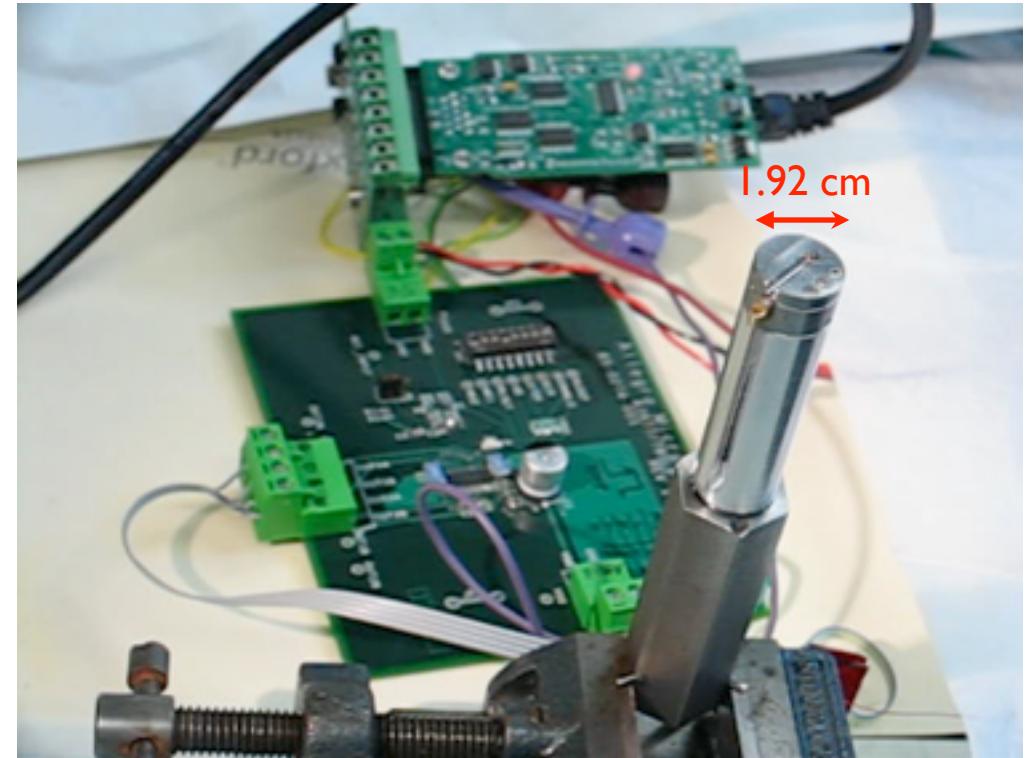
25.4 mm center-to-center spacing, 2 rotation motors



Instrument: Fiber positioners x 5000

LBNL prototype

19.2 mm center-to-center spacing



Divide into 5000 hex cells on 83 cm diameter focal plane
Each fiber is **individually actuated** with 2 Swiss motors

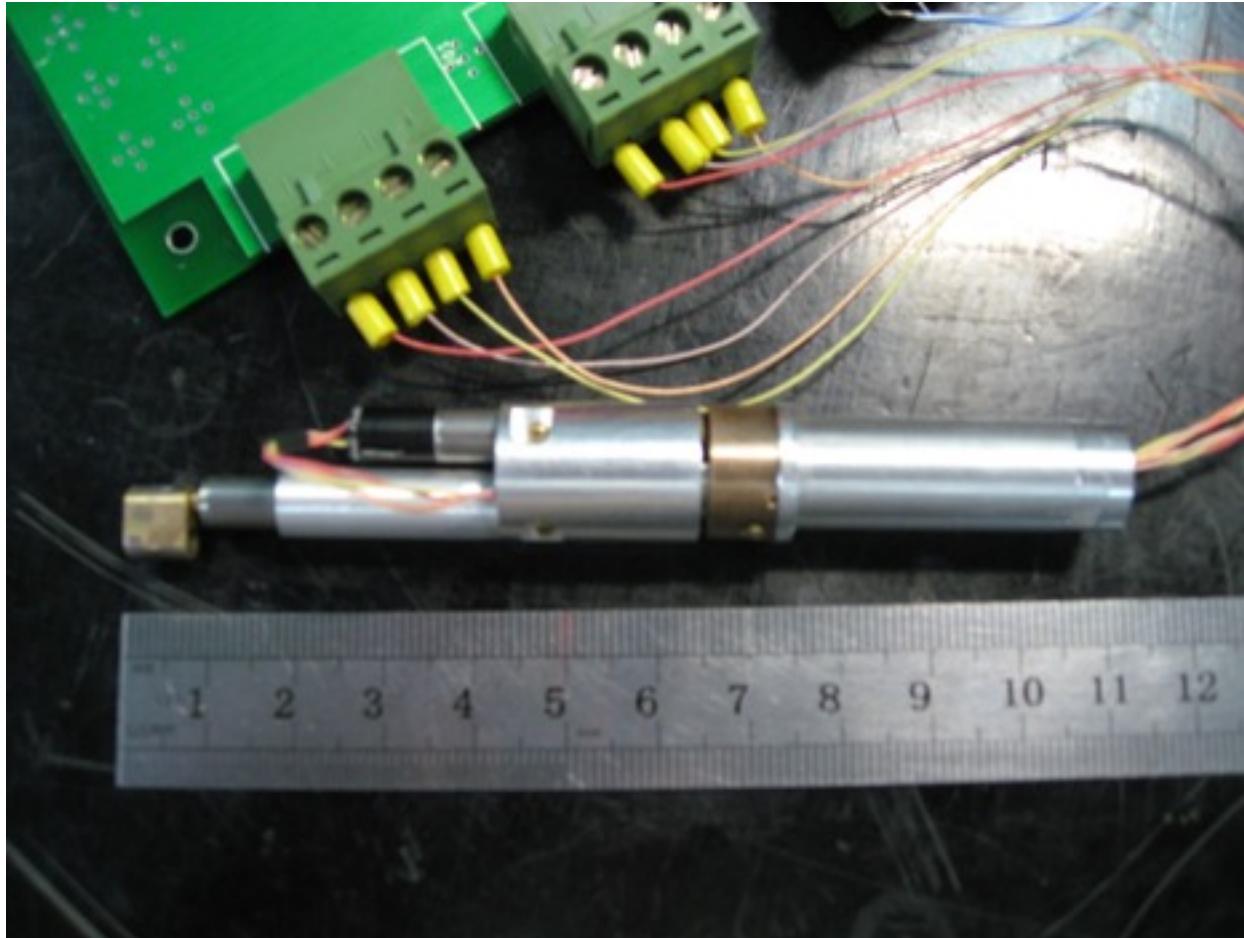
Local accuracy is only 1 part in 700 for 15 micron precision
Fiber reach extends slightly to adjacent cells - No dead space
Reconfiguration time < 1 min

Instrument: Fiber positioners x 5000

Prototype BigBOSS fiber positioner!

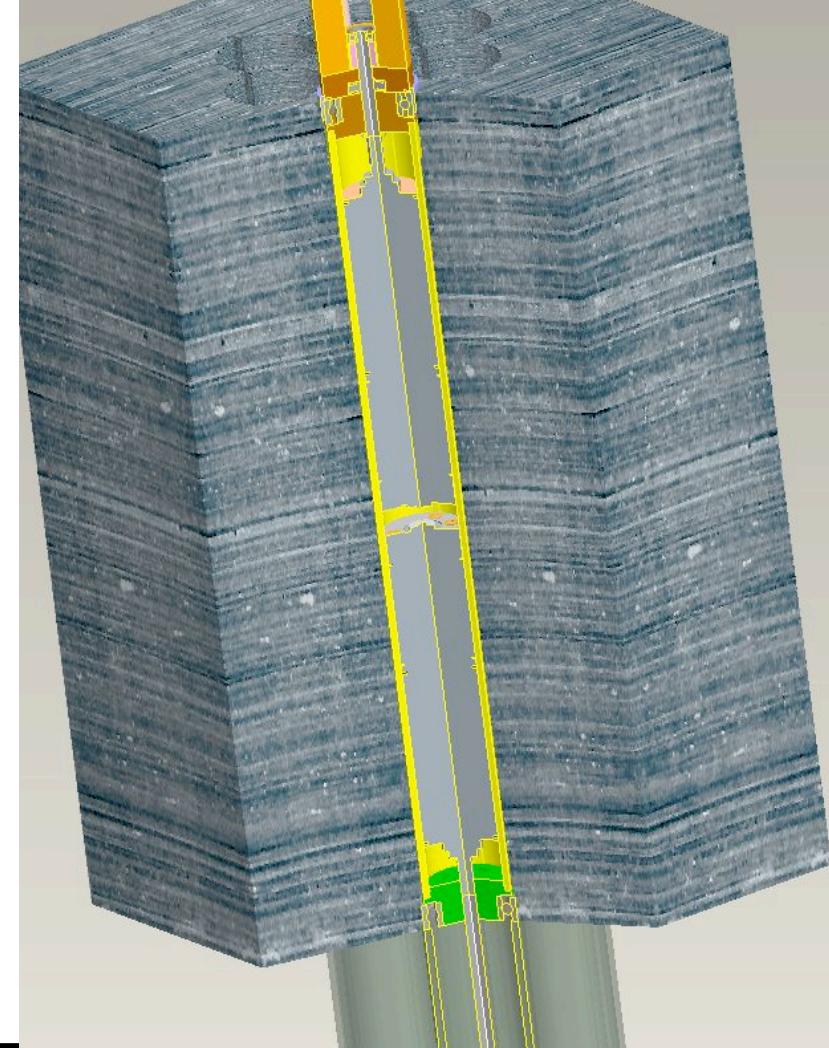
USTC, 30 Sep 2009

15 mm center-to-center



Instrument: Fiber positioners x 5000

Re-design with **11 mm** spacing center-to-center



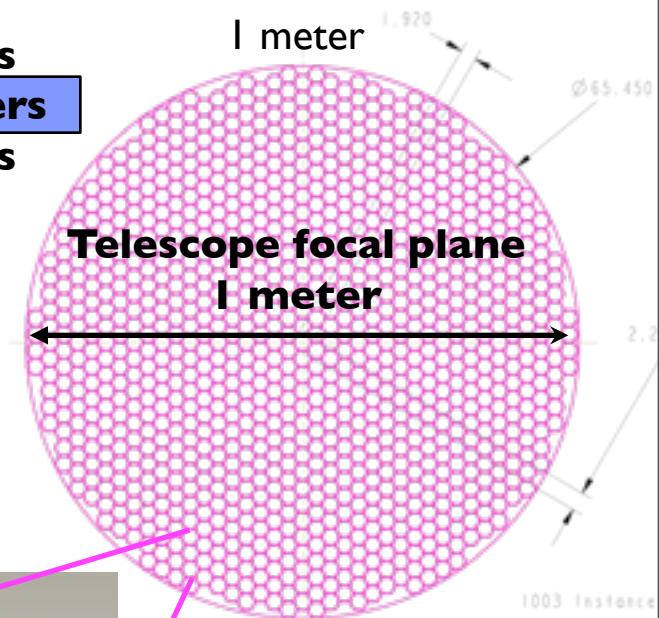
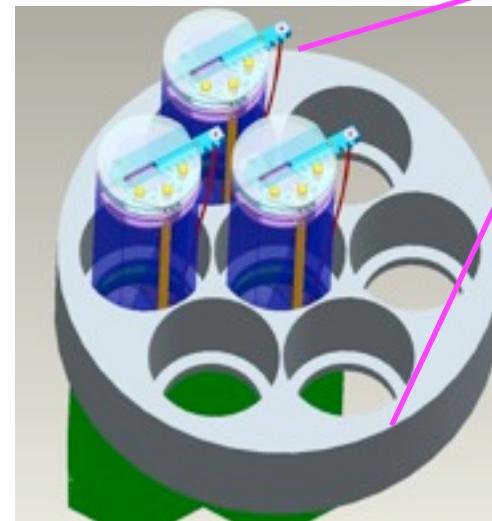
Instrument: Fiber positioners x 5000

3.0 deg field (99 cm) with 1.50 cm positioners → **4000 positioners**

2.5 deg field (82.5 cm) with 1.10 cm positioners → **5100 positioners**

3.0 deg field (99 cm) with 1.10 cm positioners → **7300 positioners**

Questions:
What size positioners?

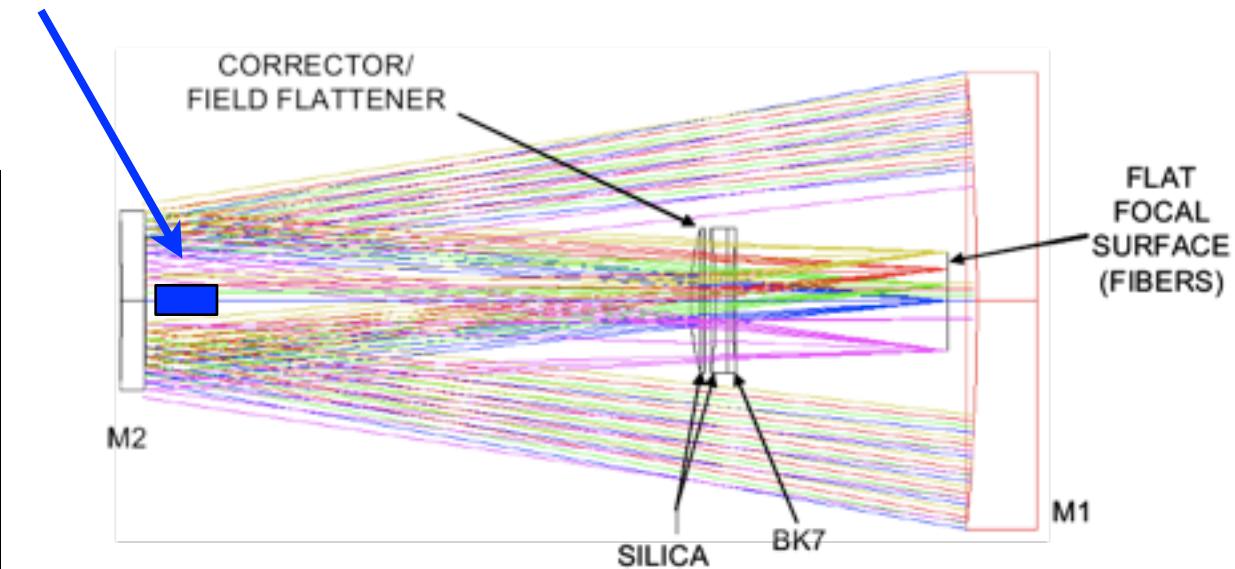
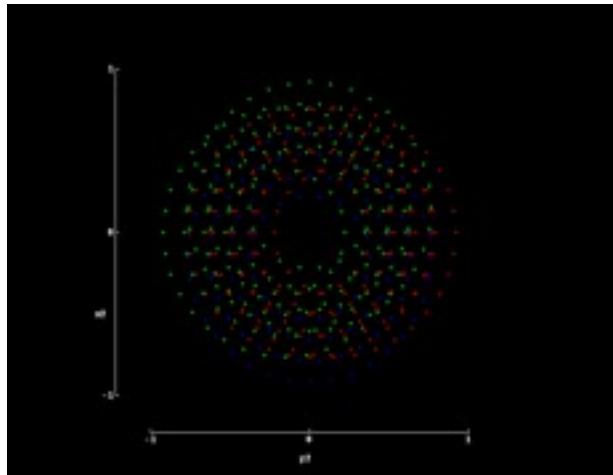


Instrument: FiberViewCam

Image fibers from near M2

Calibrates positions of all the fiber “zero positions”

Back-light fibers within the spectrograph
9k x 9k camera sits in optically-unused spot near M2



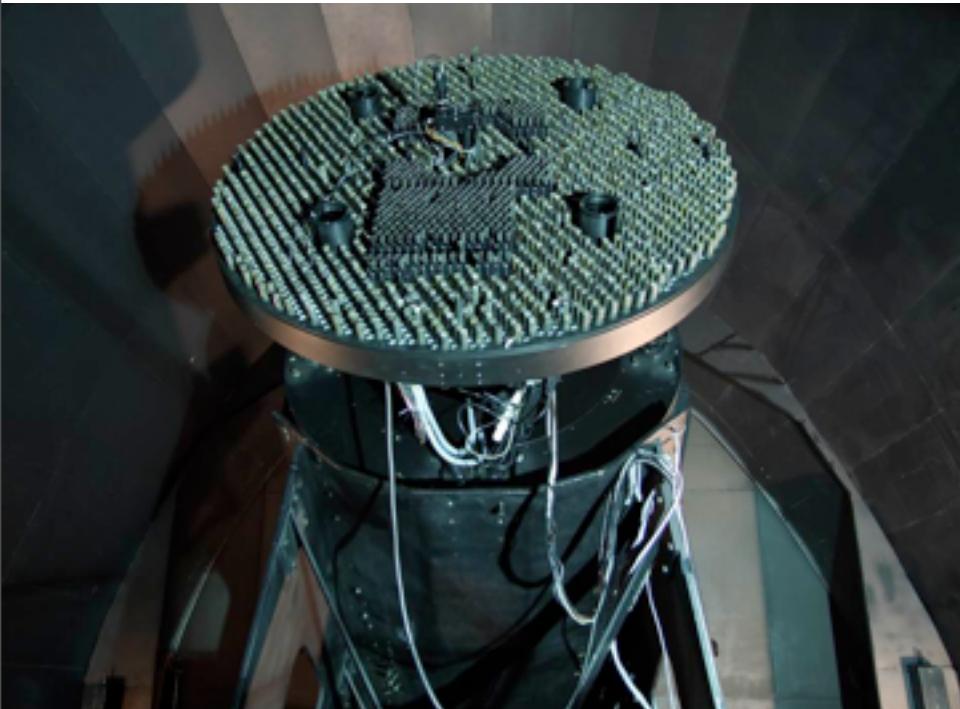
Inner 40 cm of M2 unused optically

Instrument: Acquisition + guiding

**LAMOST uses 4 CCD
cameras**



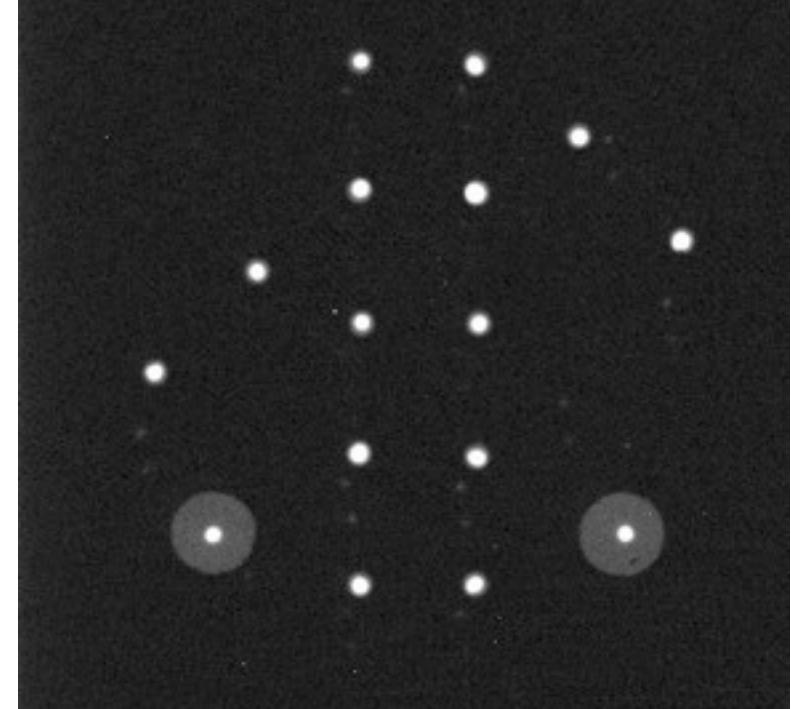
**Questions:
Acquisition
+ guiding?**



**SDSS/BOSS uses 16
coherent (plastic!) fiber
bundles**



Some are +/- 400 microns from
focus to guide in focus

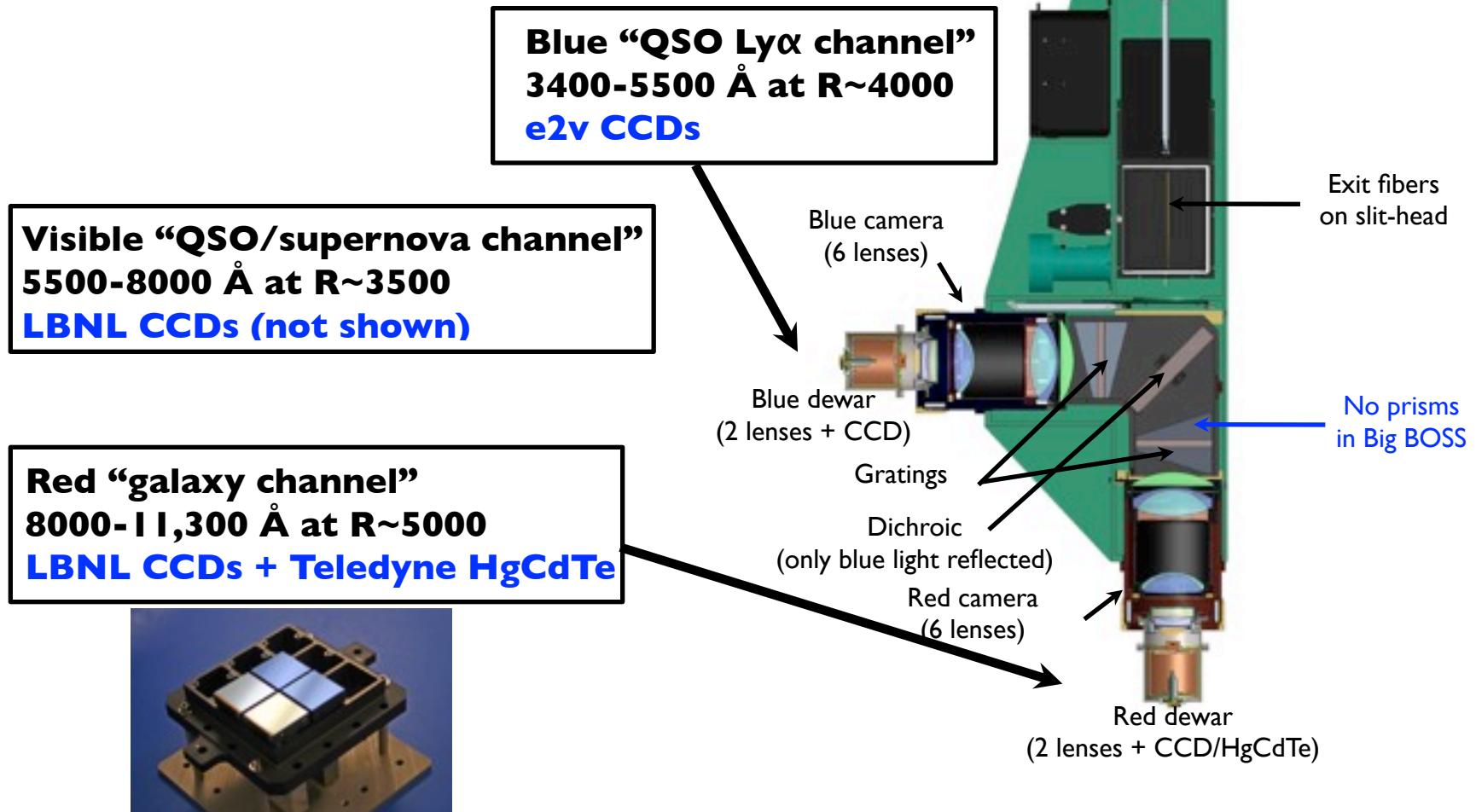


Instrument:

Spectrographs x 10

Notional design from JHU based on BOSS/WFMOS

Final design Laboratoire d'Astrophysique de Marseille (France)



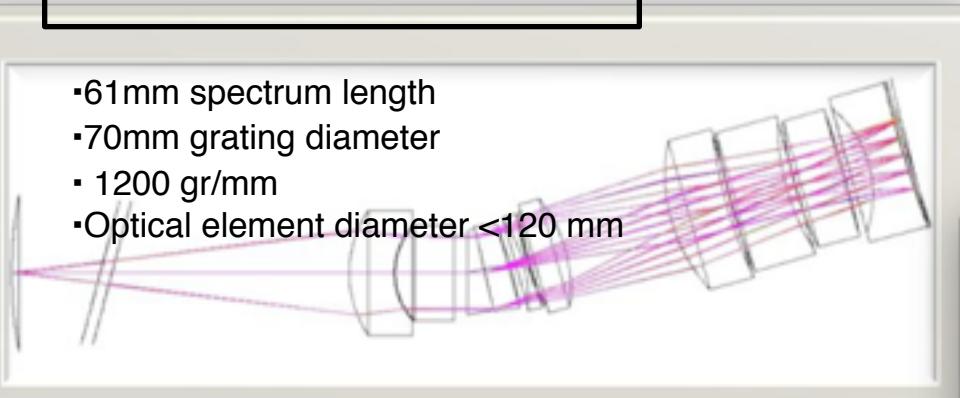
Instrument:

Spectrographs x 10

Blue “QSO Ly α channel”
e2v CCDs

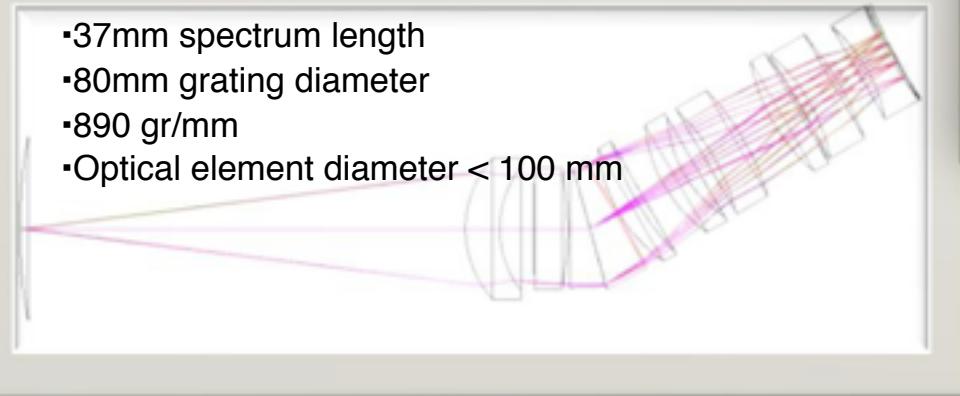
Conceptual design, Eric Prieto (LAM)
Beamsplitter + 3 refractive collimators

- 61mm spectrum length
- 70mm grating diameter
- 1200 gr/mm
- Optical element diameter < 120 mm



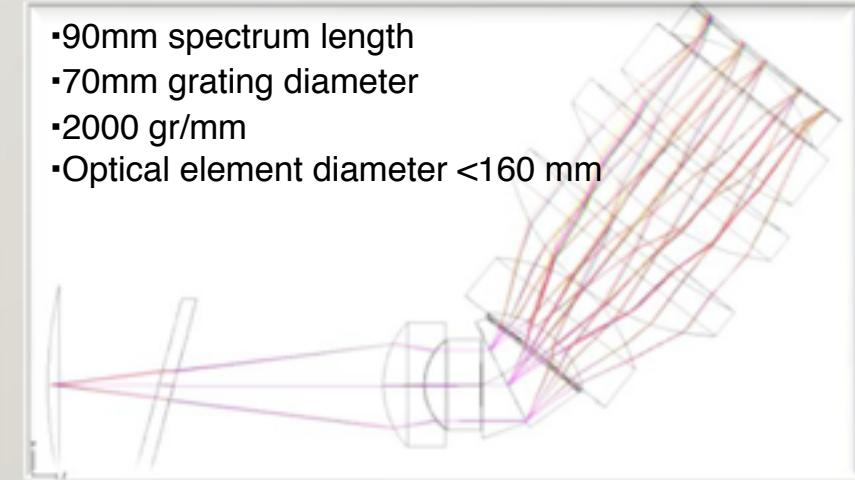
Red “galaxy channel”, R>5000
Teledyne HgCdTe

- 37mm spectrum length
- 80mm grating diameter
- 890 gr/mm
- Optical element diameter < 100 mm



Visible “supernova/QSO channel”
LBNL CCDs

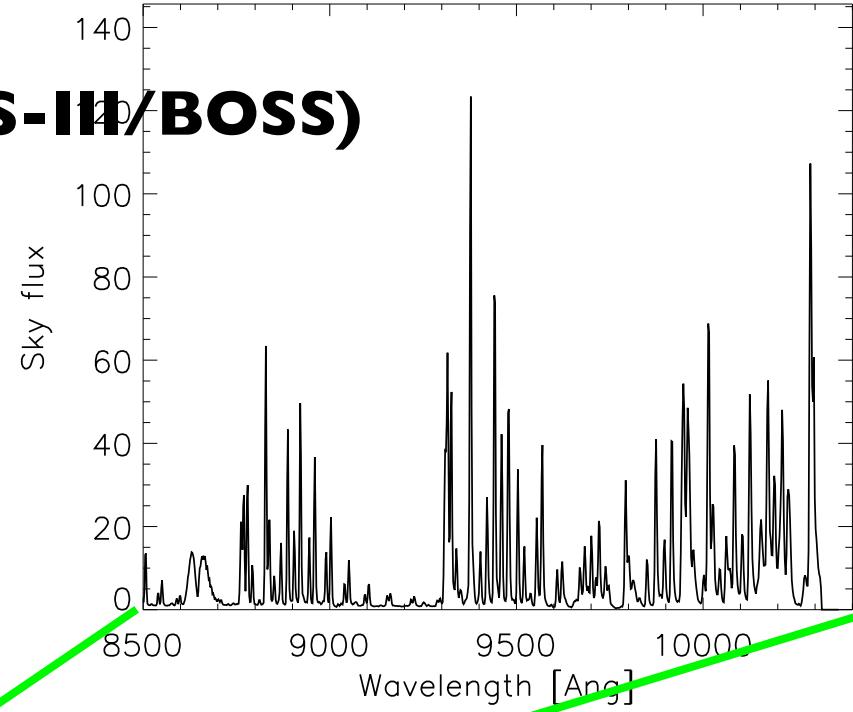
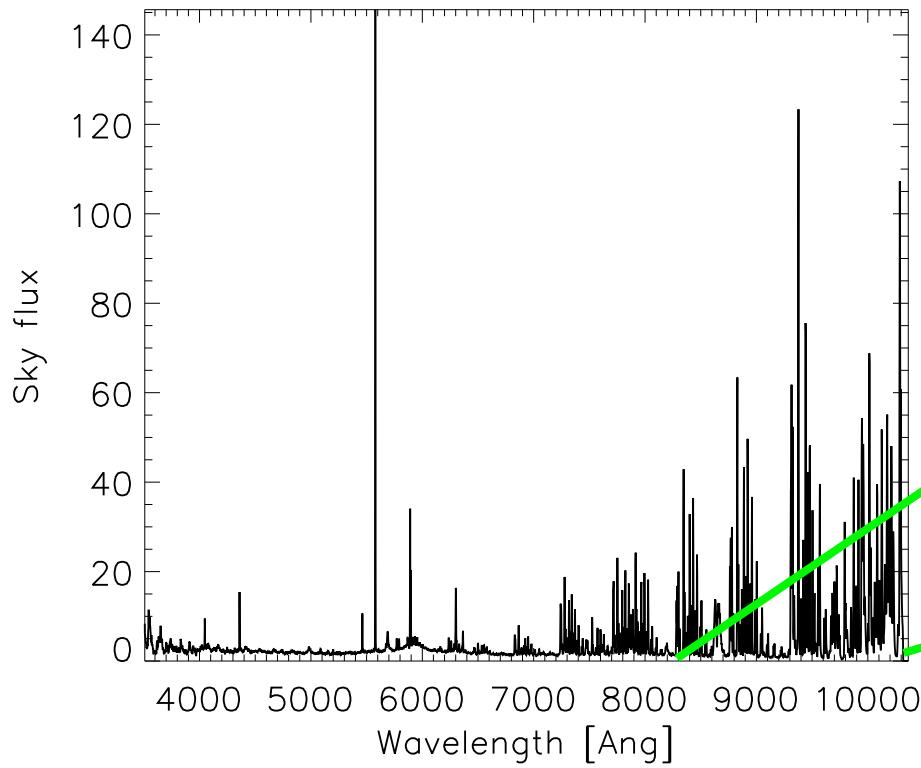
- 90mm spectrum length
- 70mm grating diameter
- 2000 gr/mm
- Optical element diameter < 160 mm



Instrument: Spectrographs x 10

Instrument designed to be a “BAO spectrograph”
Detect emission-line galaxies at $z=0.6 \rightarrow 2.0$

Sky spectrum (from SDSS-III/BOSS)

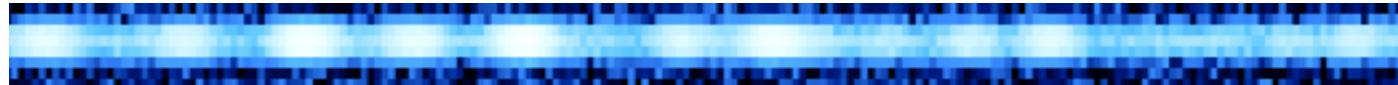


Instrument:

Spectrographs x 10

Instrument designed to be a “BAO spectrograph”
Detect emission-line galaxies at $z=0.6 \rightarrow 2.0$

Observed
Spectrum



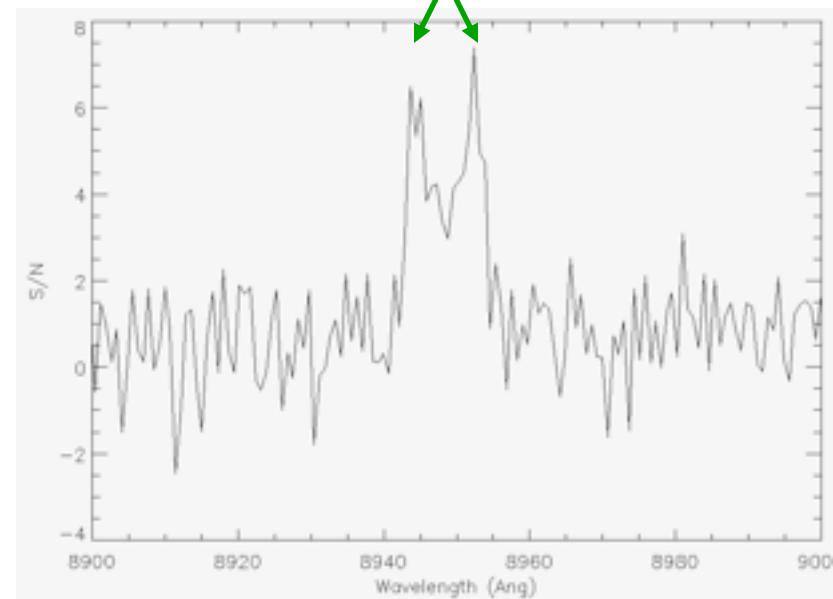
Sky-Subtracted
Spectrum



λ —————→

[OII] $\lambda 3726, \lambda 3729 @ z=1.4$

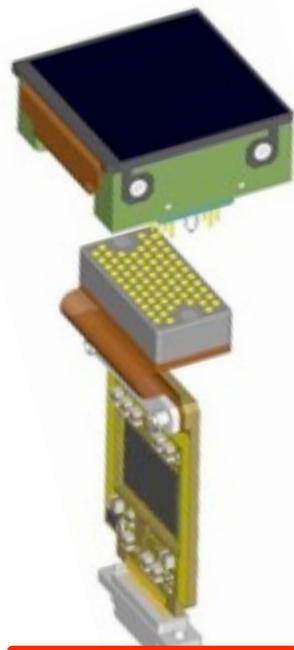
Resolution > 5000
→ Split [O II] line
→ Work between sky lines



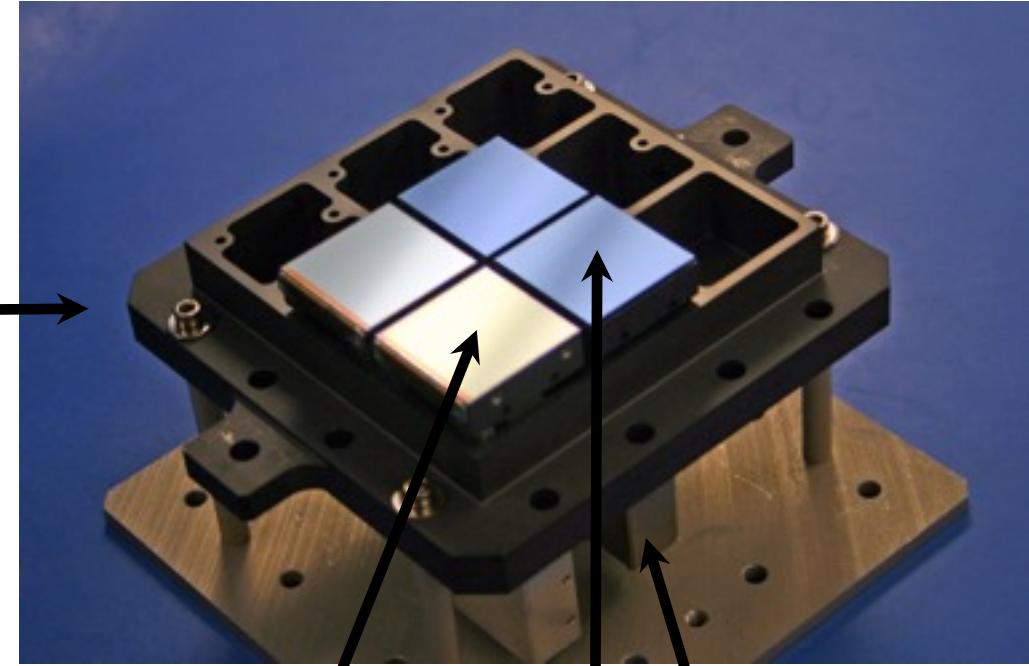
Instrument: Detectors

Optical+IR focal plane in red “galaxy channel”

Developed by LBL Microsystems Lab
for SNAP/JDEM satellite



SiC base



Infrared
HgCdTe

Optical
CCDs

Electronics Module

Cryogenic readout modules
ADC and Clock Generation
(inside dewar)

Questions:
Does the science merit IR?

Instrument:

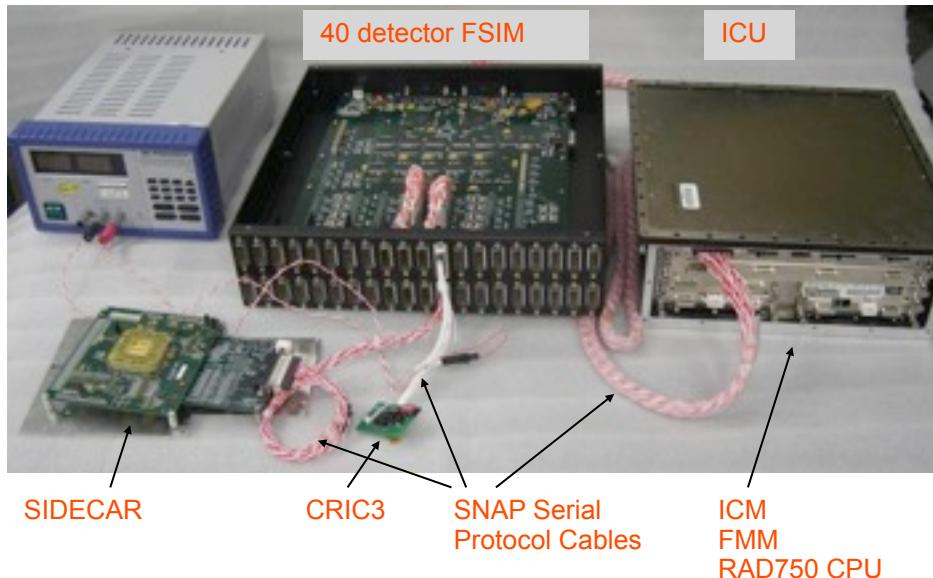
Detector readout system

Developed by Stanford/SLAC for SNAP/JDEM satellite
 Control 40 CCDs and HgCdTe in same module

GLAST memory board populated with **FLASH**



Prototype readout system



FSIM interface



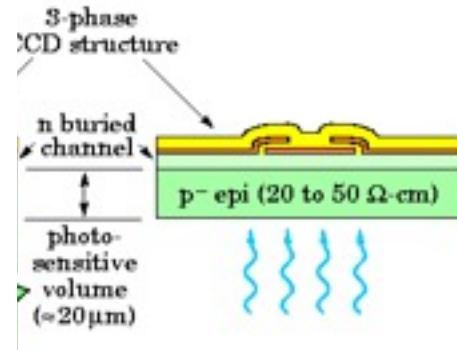
PPC CPU



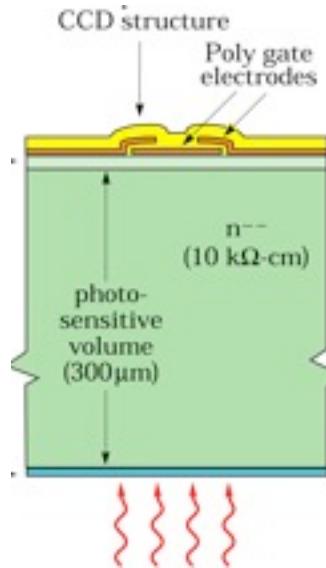
Instrument:

“Extreme silicon”

R&D to use **only silicon at $\lambda > 1$ micron**



**Standard CCD is thin ($\sim 10 \mu\text{m}$)
Poor red response**



**Fully-depleted CCD is thick
Q.E. ~50% at 1.04 μm
→ 650 μm thick !!**

**Questions:
Does the science merit IR?**

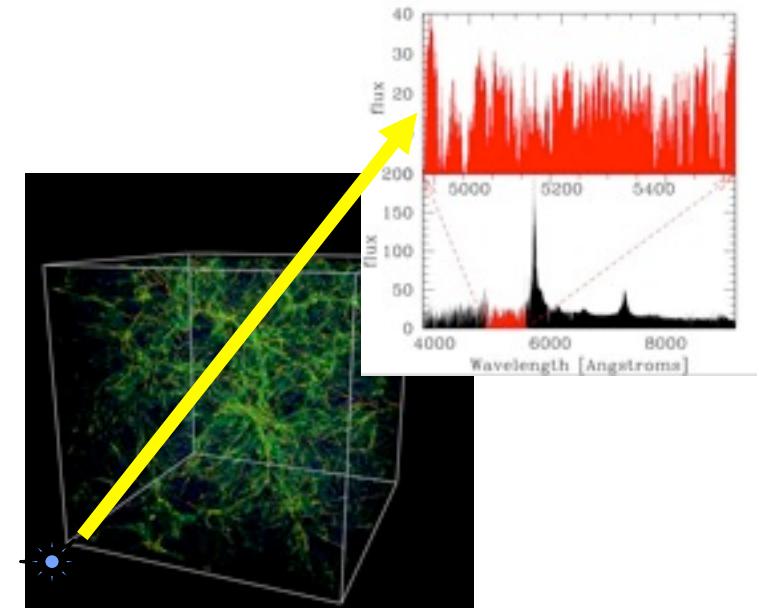
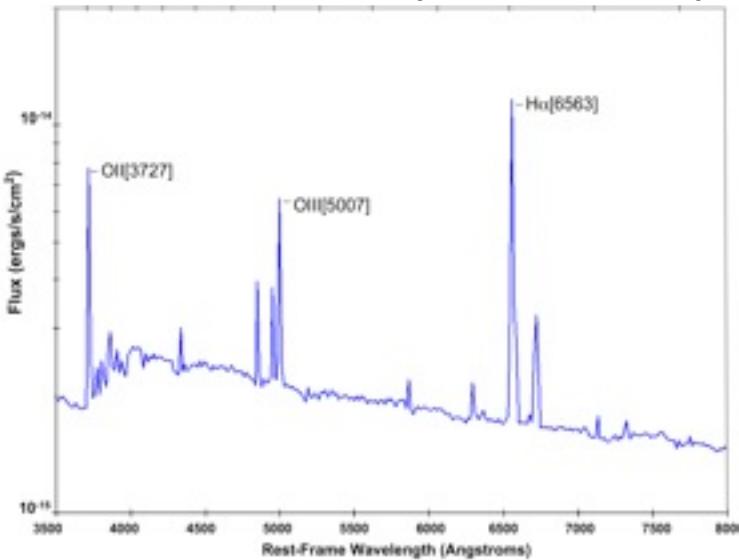
-
- I. BigBOSS science
 - II. Instrument
 - III. Imaging + Targets**
 - IV. Pilot surveys
 - V. Questions

Targets:

“Easy target survey”

- **Luminous Red Galaxies (LRGs):**
 - Selected to $z < 1$
 - Efficient BAO tracers due to large bias
- **Emission-line galaxies:**
 - Selected $0.7 < z < 2.0$ at source density of $dn/(dz \text{ deg}^2) = 2000$
 - Redshifts from [O II], [O III] emission lines, $R \sim 5000$
- **QSOs:**
 - Selected $2 < z < 3.5$
 - 3-D density map from Ly-alpha forest

Questions:
Add $1 < z < 2$ QSOs?



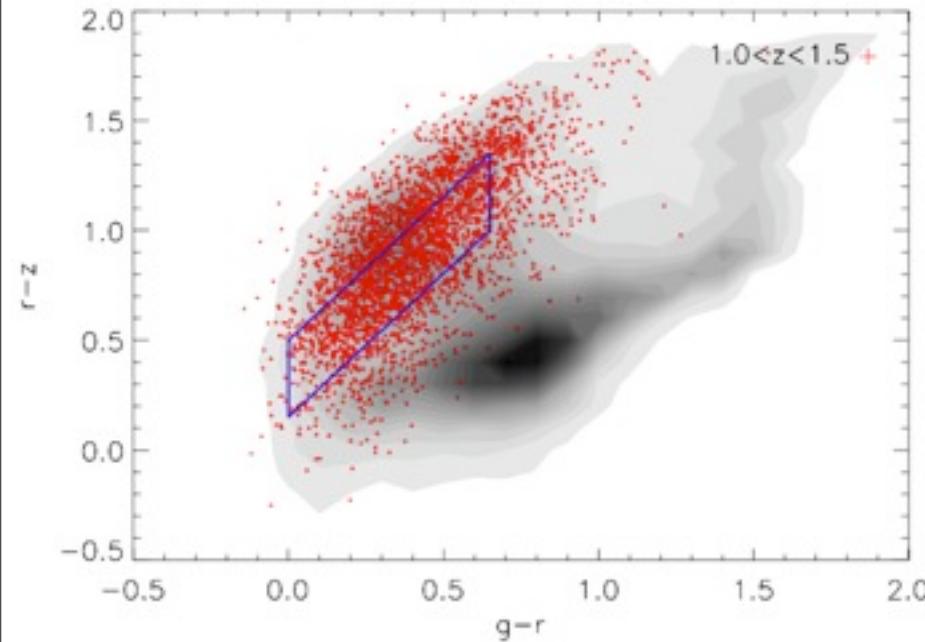
Targets:

Emission-line galaxies $0.7 < z < 2$

Courtesy: **Nick Mostek**

$z < 1.6$ sample

grz-selected

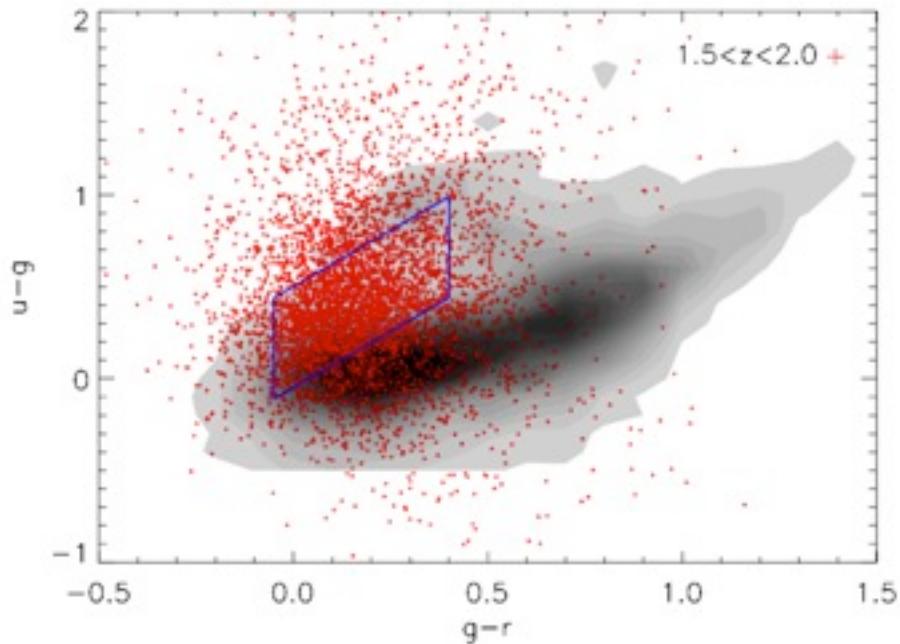


PTF $g+r$ bands

+ PanSTARRS-1 z -band

$1.5 < z < 2$ sample

ugr-selected



PTF $g+r$ bands

+ CFHT u -band (proposed)

Synthetic magnitudes are degraded using photometric errors from Palomar Transient Factory (gr), Pan-STARRS-1 (iz), and a CFHT-like survey (u)

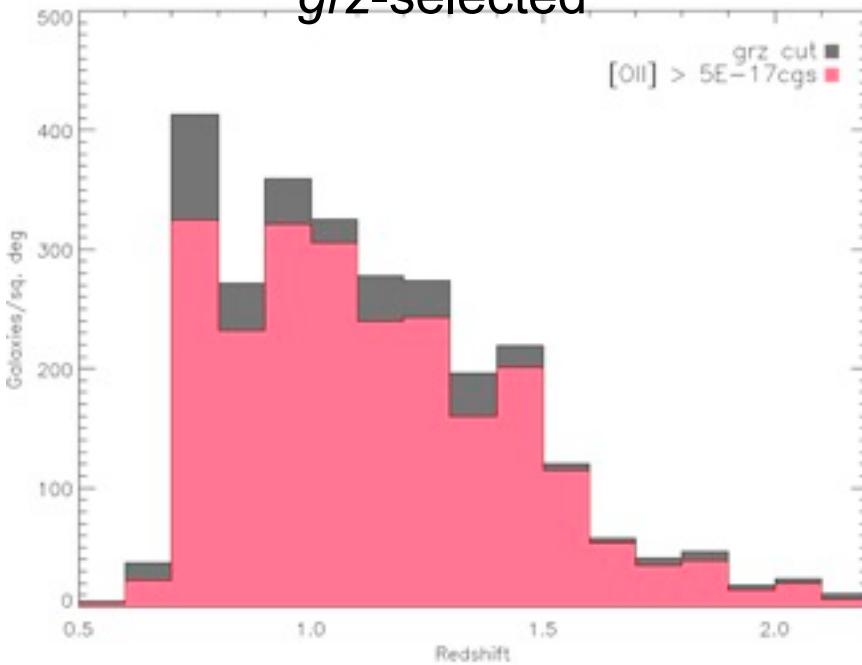
Targets:

Emission-line galaxies $0.7 < z < 2$

Courtesy: *Nick Mostek*

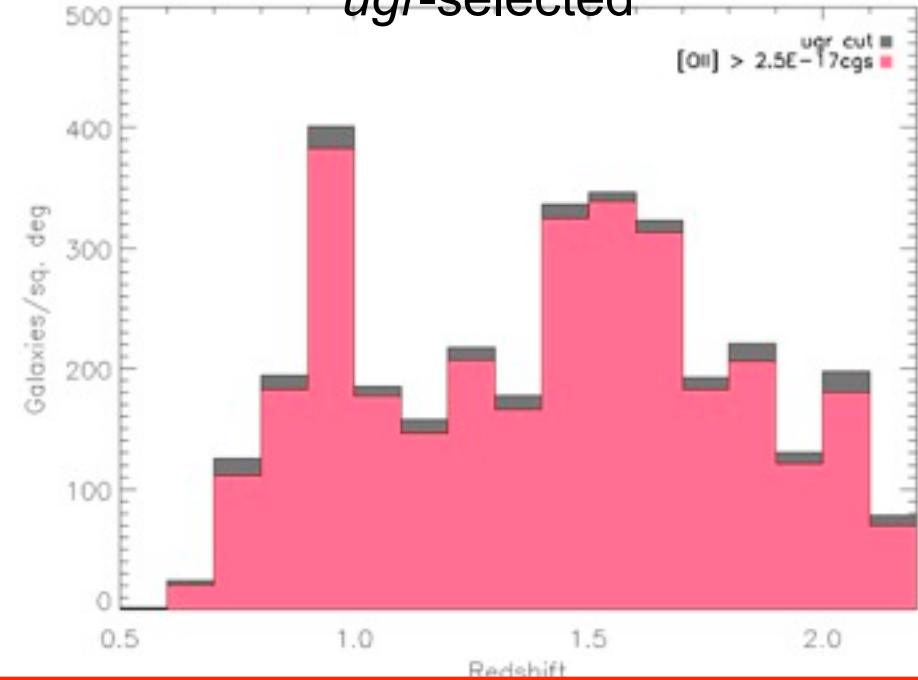
$z < 1.6$ sample

grz-selected



$1.5 < z < 2$ sample

ugr-selected

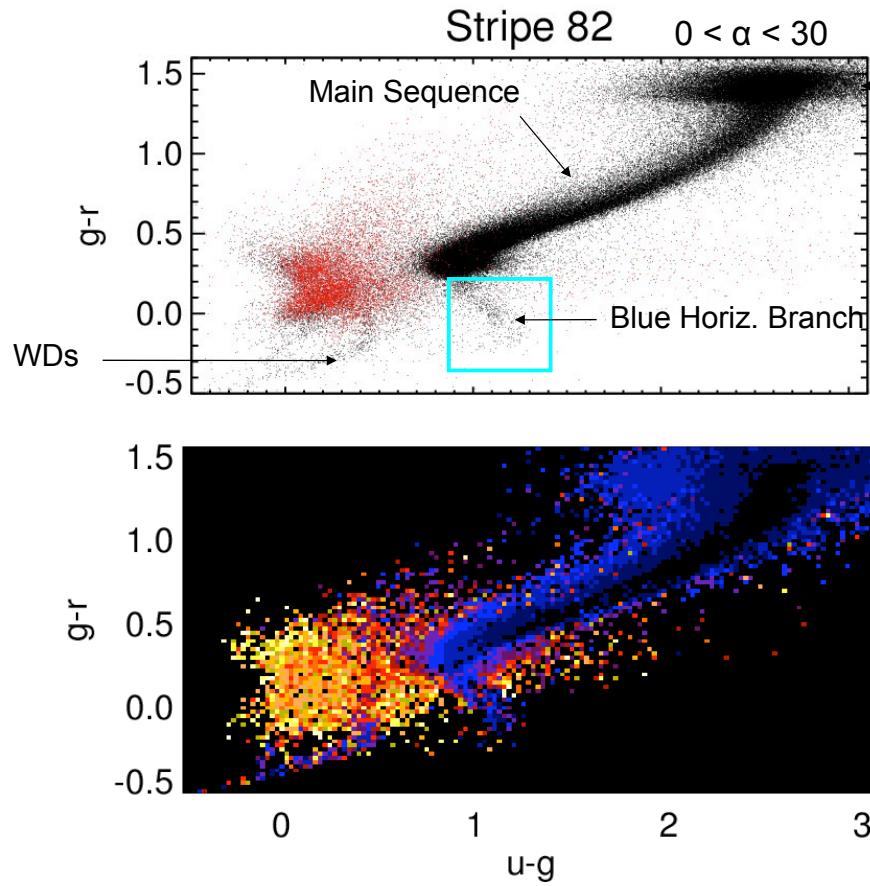


Questions:

Does the science merit IR $z \rightarrow 2$, or extreme silicon $z \rightarrow 1.7$?
 Palomar Transient Factory deep enough in g+r?
 u-band or i/z-band?

Targets: QSOs

QSO targeting very problematic for BOSS
 “Easy” for BigBOSS, with variability info



Questions:
**QSO targets from colors
 or variability?**

QSO contamination from stars expected at 50%

Testing different techniques:

- * Likelihood (LBL)
- * Kernel density estimation (Drexel)
- * Neural nets (Paris)

Other data sets:

- * Variability (Palomar QUEST + PTF)
- * Infrared (UKIDDS)
- * UV (GALEX)

-
- I. BigBOSS science**
 - II. Instrument**
 - III. Imaging + Targets**
 - IV. Pilot surveys**
 - V. Questions**

Near-future data sets:

I. Keck DEEP2 survey

Em. line galaxies $0.7 < z < 1.4$

II. Keck extension

Em. line galaxies $1.4 < z < 1.75$

III. BOSS -- first light Sep 2009

Absorp.-line galaxies $0 < z < 0.7$

Tests VPH gratings, LBL CCDs

IV. FIRE (Magellan) and X-Shooter (VLT)

Near-infrared spectroscopy at $R \sim 5000$

Em. line galaxies $1 < z < 2+$

Questions:

Study of sky brightness?

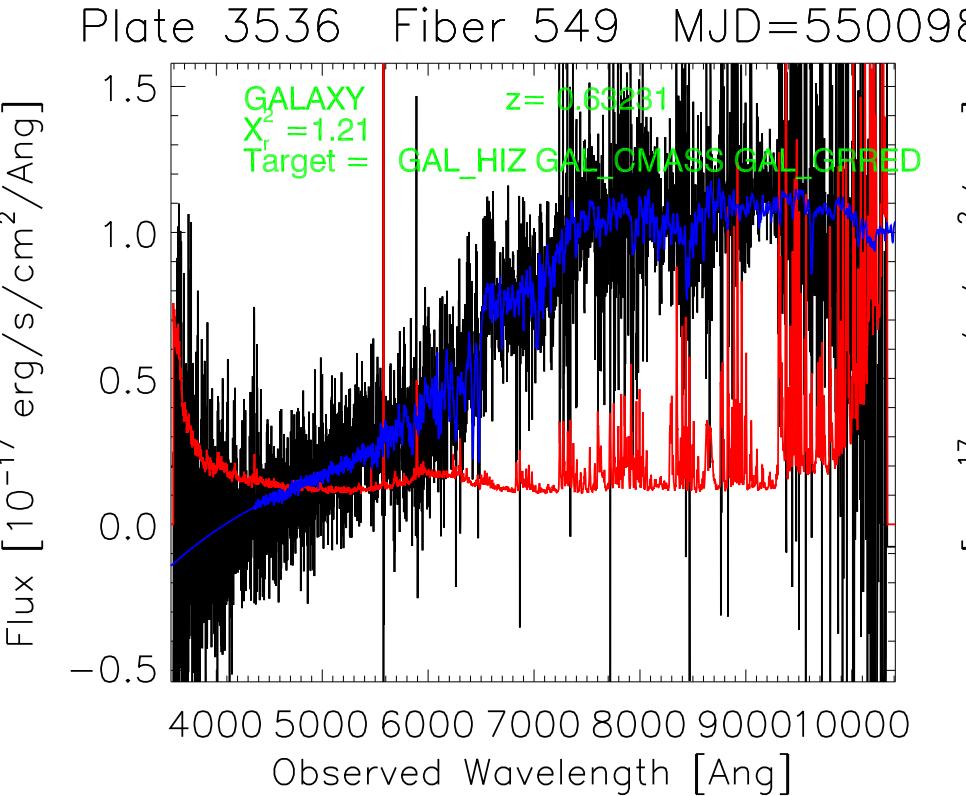
Limits of fiber sky-subtraction?

Pilot surveys

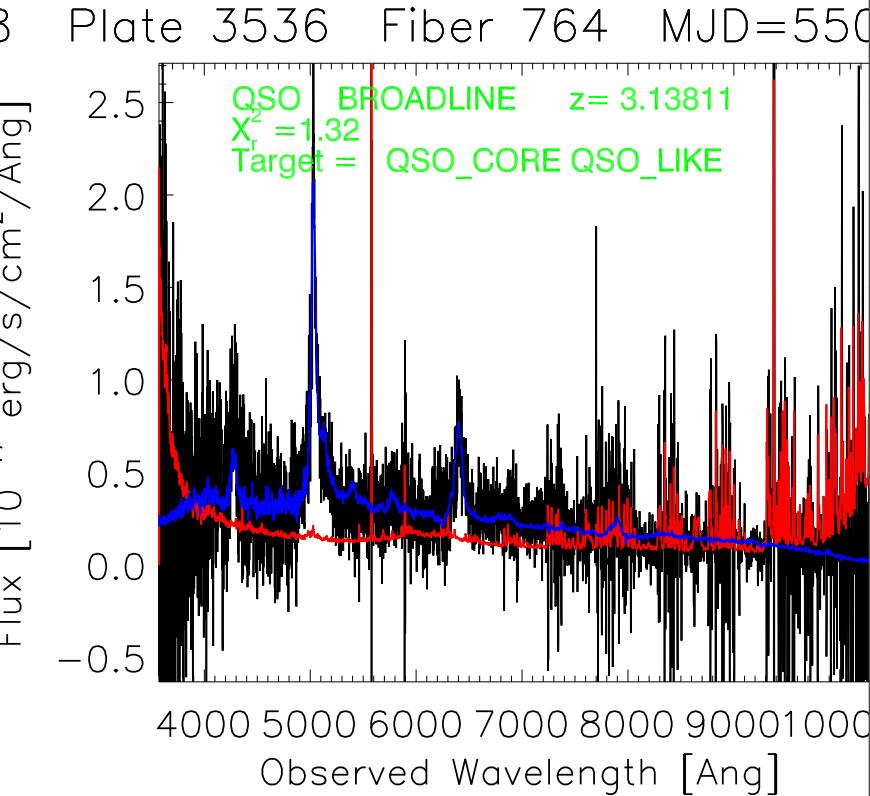
III. BOSS -- first light Sep 2009

We're the “noisy data” survey

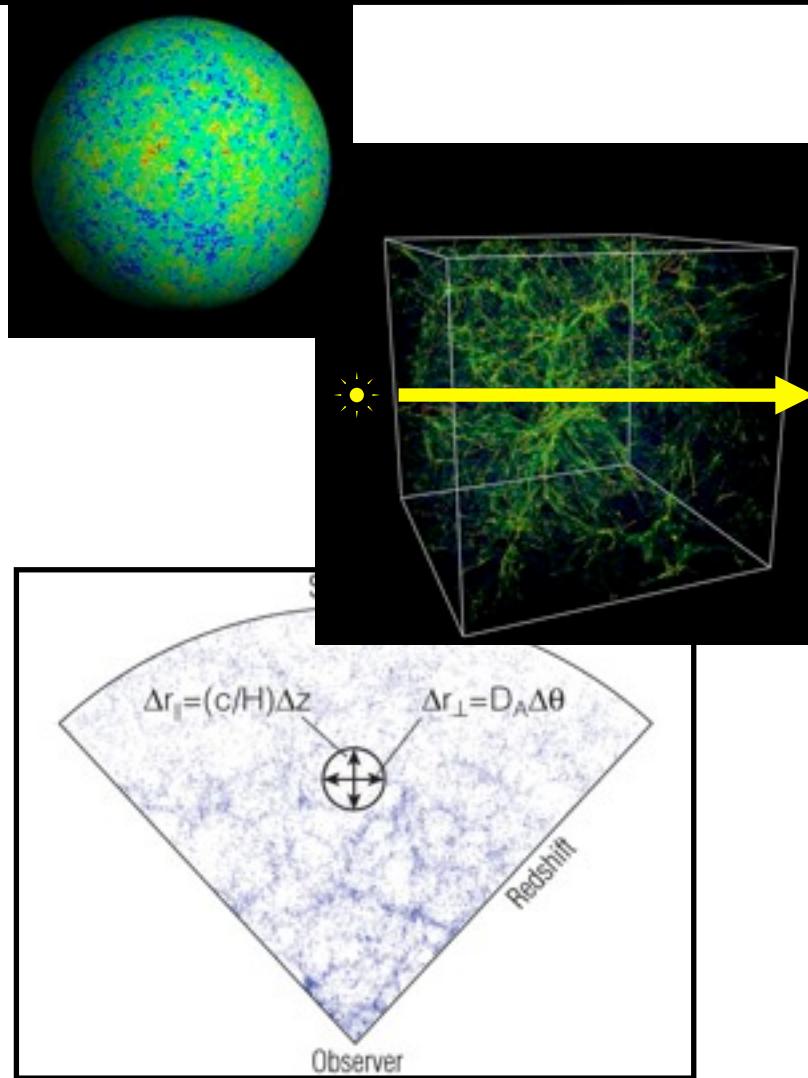
Galaxy z=0.6



QSO z=3.1



-
- I. BigBOSS science**
 - II. Instrument**
 - III. Imaging + Targets**
 - IV. Pilot surveys**
 - V. Questions**

Status**Re-optimize targets w/"extreme silicon"** **$z=1088$** **$z=3.5$**

↑
**QSO LyA
forest**

 $z=2$ **$z=1.5$** **$z=1$**

↓
**Em. line
galaxies**

 $z=0$

Low-bias High-bias

↑
QSOs
↓
LRGs
↓

Science Questions:

Desired n/volume?

Multiple tracer populations/bias? LRGs, QSOs, em. line gals, LyA

Redshift precision (QSOs)?

Does the science merit IR?

Add $1 < z < 2$ QSOs?

N-body simulation requirements?

Optics Questions:

Lens cell tolerances?

ADC necessary?

AR coatings at 1.2-m?

Instrument Questions:

What size positioners?

Acquisition + guiding?

Target Questions:

Extreme silicon $z \rightarrow 1.7$?

Palomar Transient Factory deep enough in g+r? u-band or i/z-band?

QSOs from colors or variability?

Pilot survey Questions:

Study of sky brightness?

Limits of fiber sky-subtraction?